Detailed Analysis of Horizontal Wave Parameters Using Radio Occultation Data

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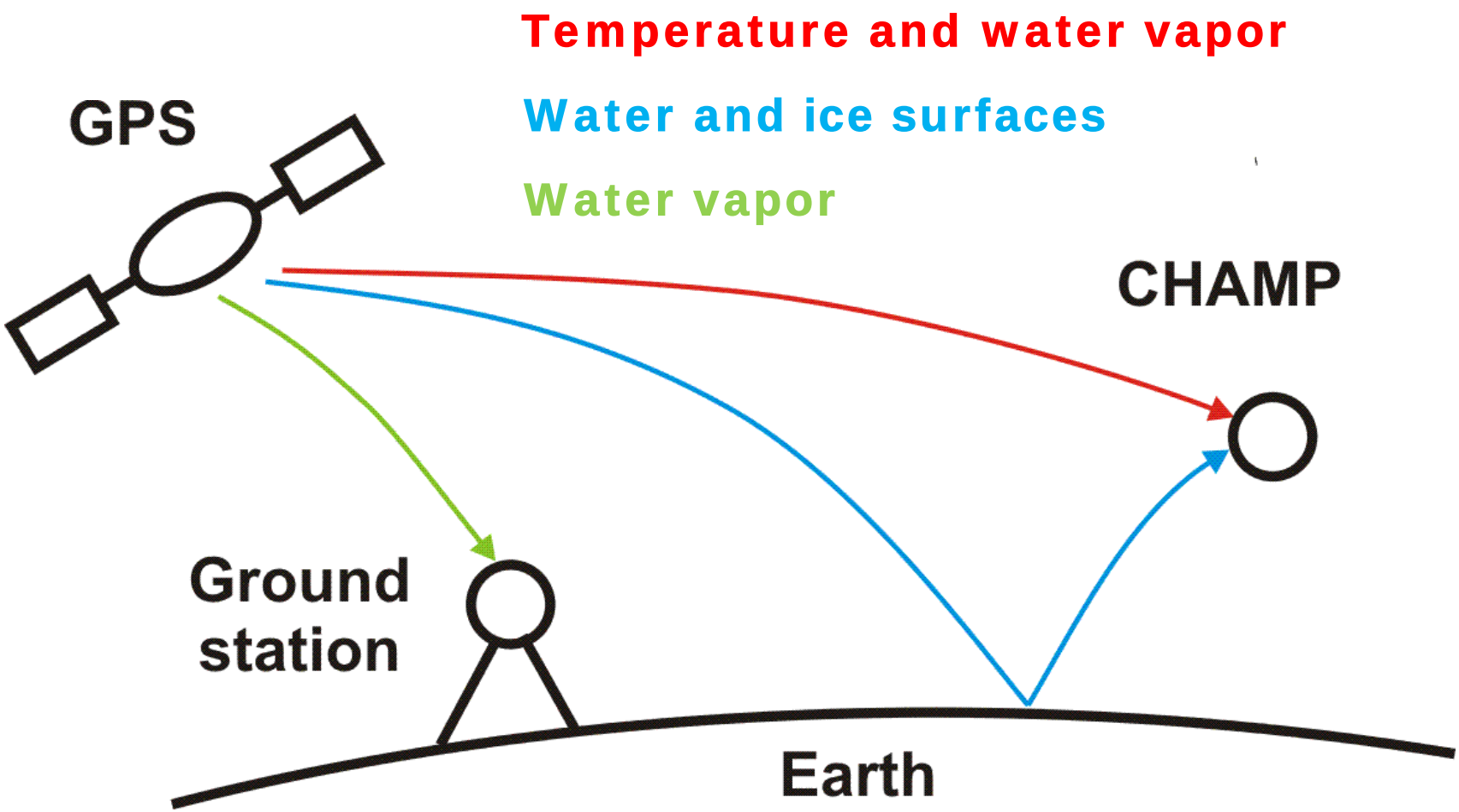
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The CHAMP and GRACE team (GFZ)
The COSMIC team (UCAR)

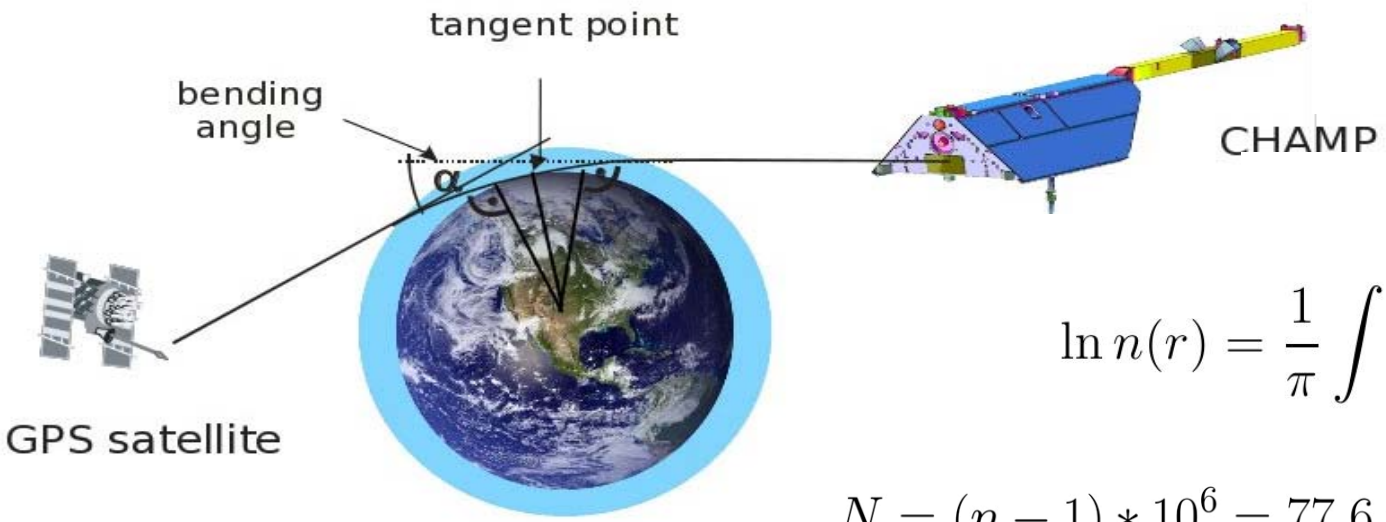
GFZ
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ASSOCIATION

POSITIONING AND REMOTE SENSING WITH GPS



GPS RADIO OCCULTATION MEASURING PRINCIPLE



$$\ln n(r) = \frac{1}{\pi} \int da' \frac{a(a')}{\sqrt{a'^2 - a^2}}$$

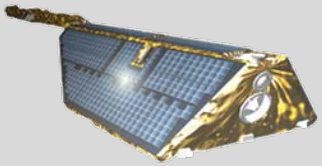
$$N = (n-1) * 10^6 = 77.6 * \frac{p}{T} + 3.73 * 10^5 \frac{p_w}{T^2}$$

n: refractive index
N: refractivity
T: temperature
p: pressure
p_w: water vapor pressure

Global coverage
High vertical resolution
Weather independent

Calibration free
Long-term stability

GPS RADIO OCCULTATION MISSIONS



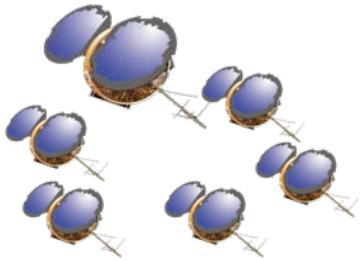
2001 – 2008

CHAMP (09/2010)



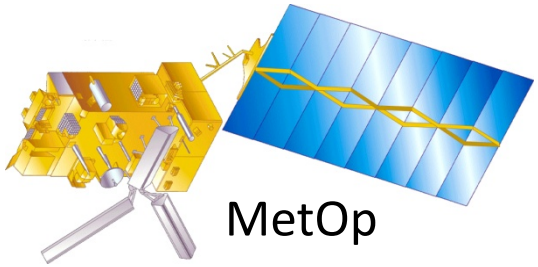
since 2006

GRACE



since 2006

COSMIC/FORMOSAT-3



since 2006

MetOp



since 2008/10

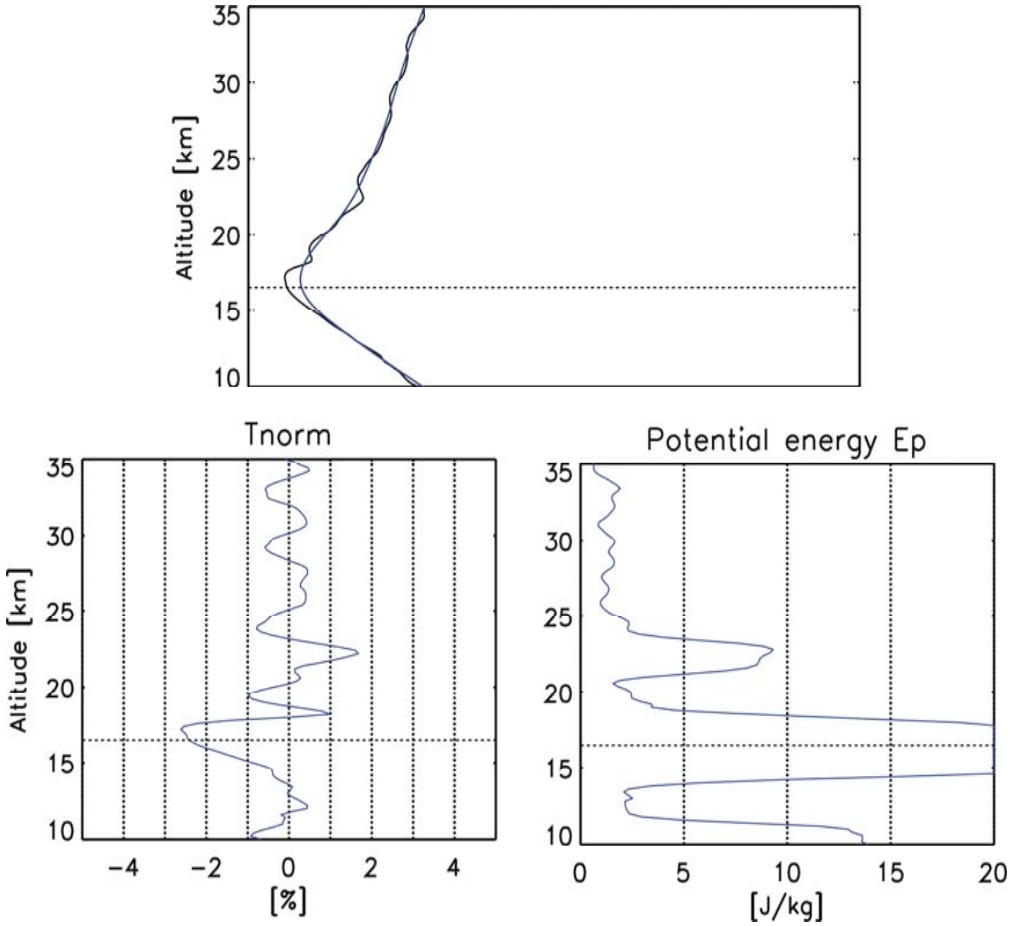
TerraSAR-X / Tandem-X

GRAVITY WAVE ANALYSIS

$$T'(z) = T(z) - \overline{T}(z)$$

$$N_z^{\,2}(z) = \frac{g}{\overline{T}} \cdot \left(\frac{\partial \overline{T}}{\partial z} + \frac{g}{c_p} \right)$$

$$E_p(z) = \frac{1}{2} \cdot \frac{g^2}{N^2} \cdot \left(\frac{T'}{\overline{T}} \right)^2$$



GRAVITY WAVE ANALYSIS

Momentum Flux

$$F = \frac{1}{2}\rho\frac{k_h}{m}\left(\frac{g}{N_z}\right)^2 \cdot \left(\frac{T'}{\overline{T}}\right)^2 = \frac{k_h}{m}\rho \cdot E_p$$

Goal is a global distribution of the momentum flux (MF) from radio occultation temperature profiles

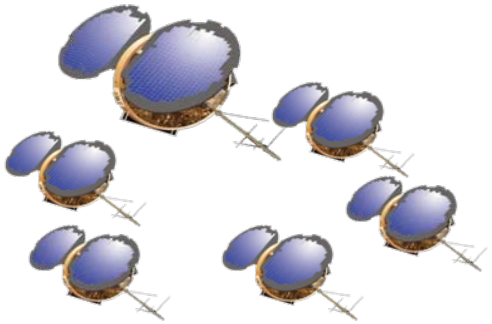
FROM RO-MEASUREMENT TO MOMENTUM FLUX DETERMINATION

What we have:

- Density, potential energy and vertical wavenumber (at all altitudes) based on vertical temperature profiles

What we need:

- The horizontal wavenumber. Can be determined using more then one vertical profile.
- Close-by measurements in time and space!



COSMIC/FORMOSAT-3

Constellation Observing System for Meteorology, Ionosphere & Climate

- Six LEO satellites mission
- Started April 2006 (all LEO's on one rocket)
- Early orbit phase (satellites → occultations close together)
- After 20 month the satellites reached final configuration
- COSMIC provides up to 2500 profiles a day

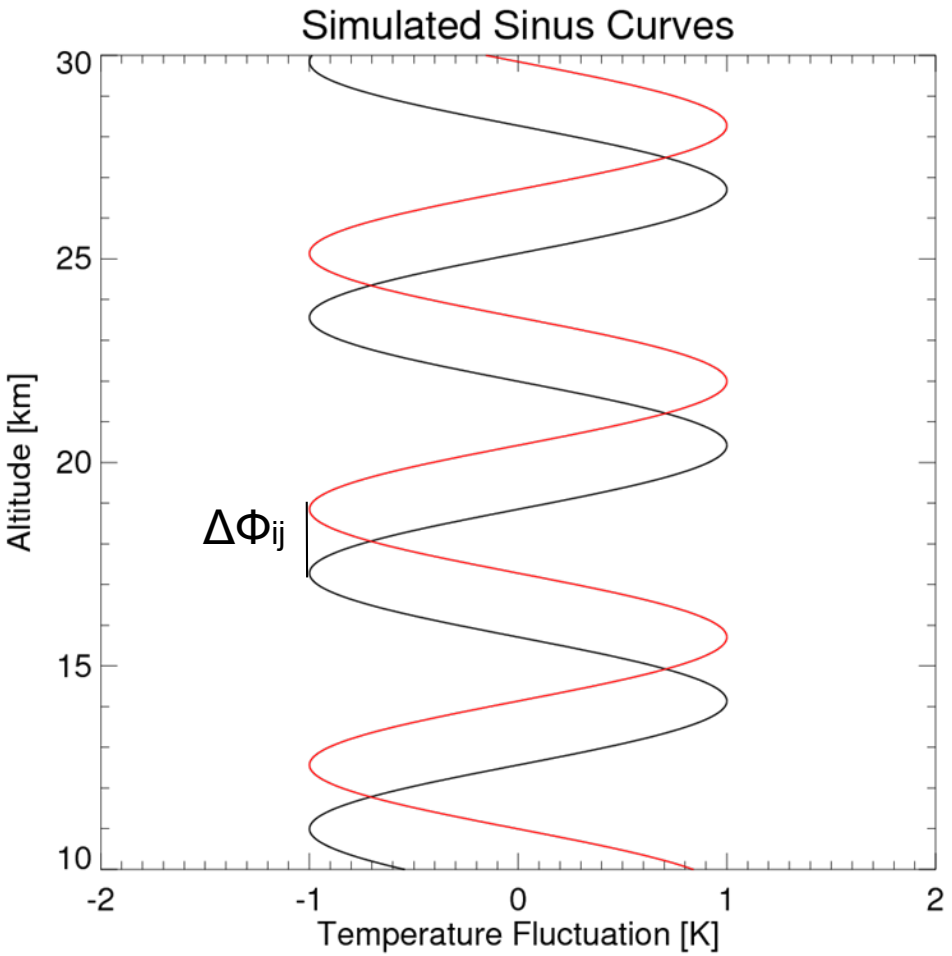
HORIZONTAL WAVELENGTH AFTER ERN ET AL. 2004

- Horizontal wavelength from two or more adjacent profiles when:
  - All profiles belong to the same sinusoidal wave
  - One time and one altitude

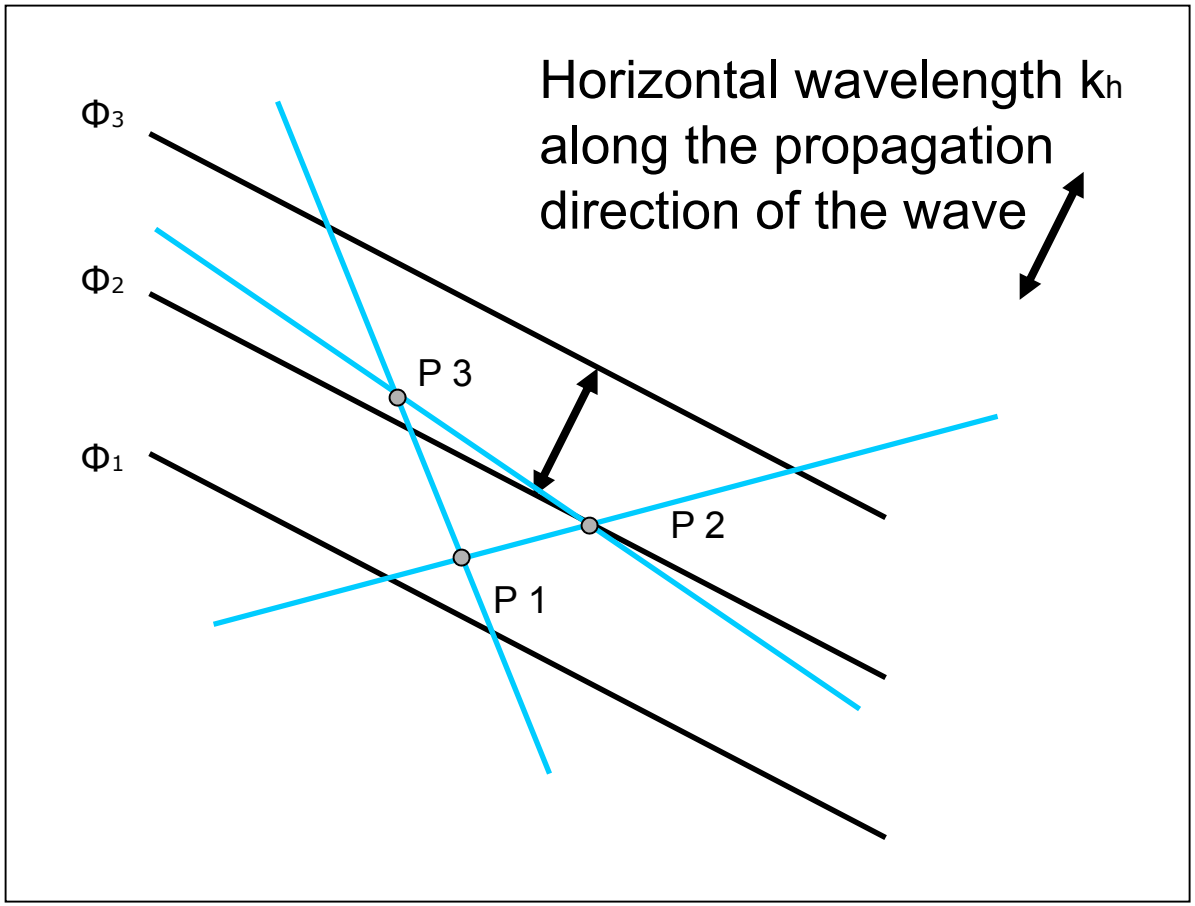
$$T'(x_h, z, t) = \bar{T}(z)\, sin(\phi)$$

- Horizontal wavenumber k_h is given by the quotient of the phase shift $\Delta\Phi_{ij}$ (between the two profiles) and their horizontal distance Δx_{ij}

$$k_h = \frac{\Delta\phi_{i,j}}{\Delta x_{i,j}}$$



TRIADS



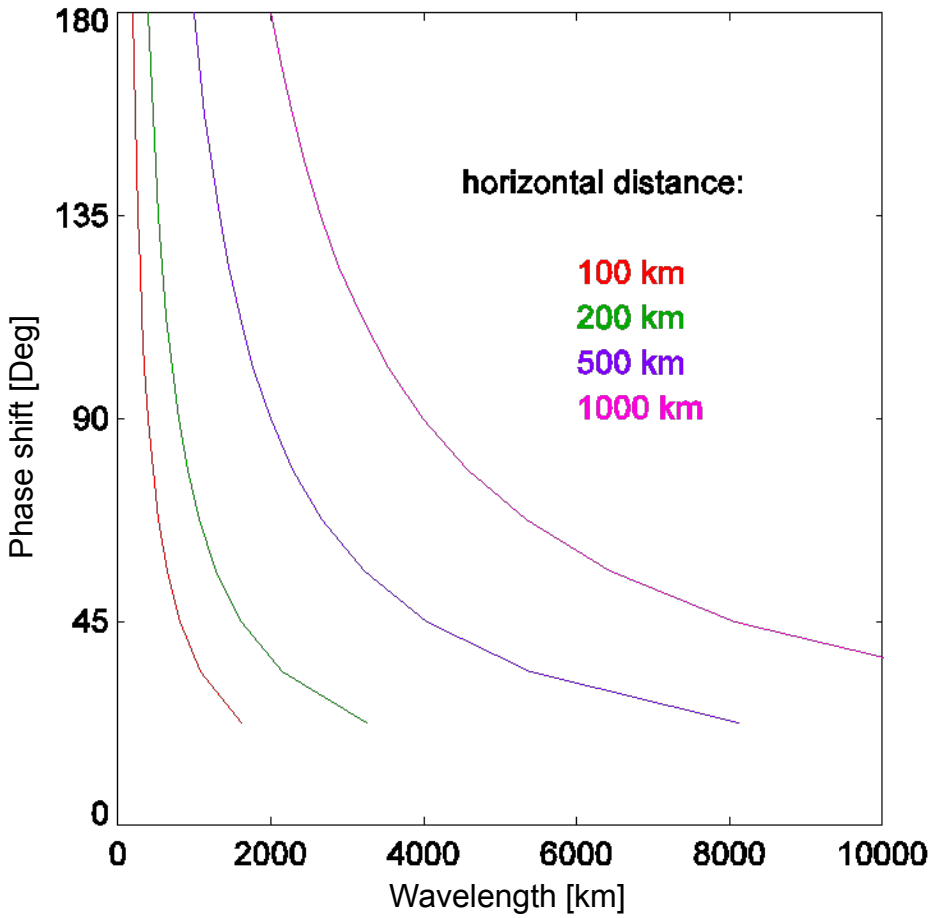
Theoretical chart for horizontal wavelength determination using three independent GPS RO profiles

Blue lines show the direction in which the horizontal wavelength is derived using only two measurements

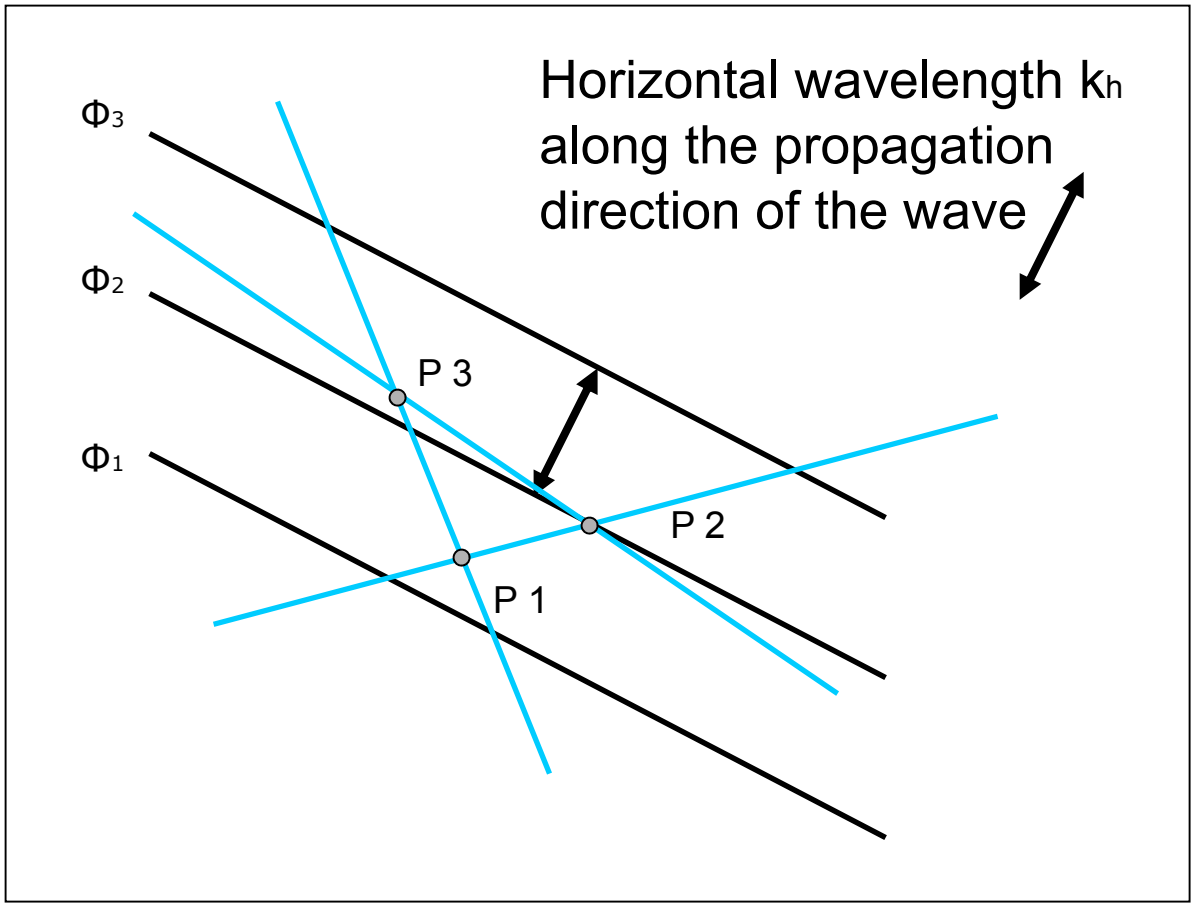
STATISTICAL ANALYSIS

- Statistic of the horizontal wavelength when changing the horizontal distance (colored lines)
- When you decrease the distance you can see shorter waves with and detect them with smaller phase shifts
  - When the phase shift gets to small, the wavelength approaches infinity

→ There is no wave!



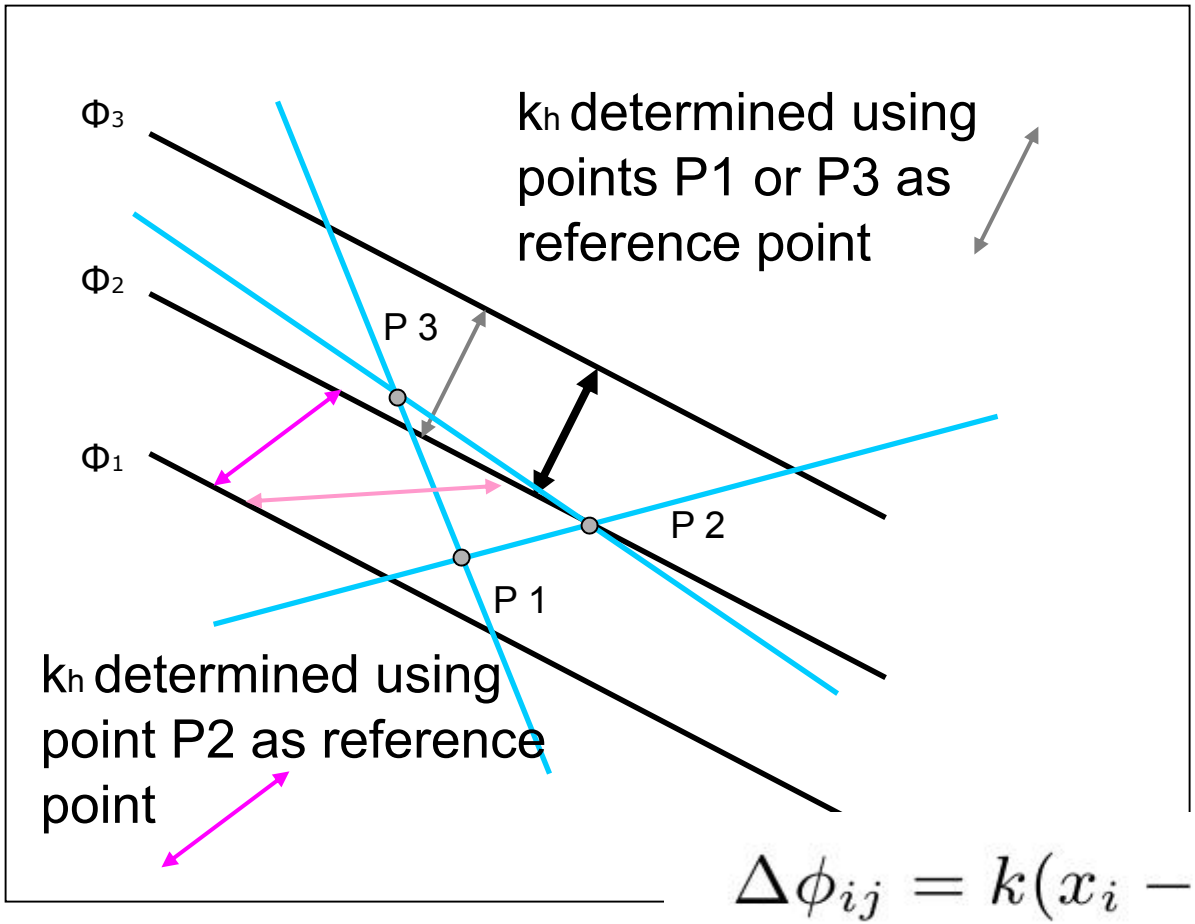
TRIADS



Theoretical chart for horizontal wavelength determination using three independent GPS RO profiles

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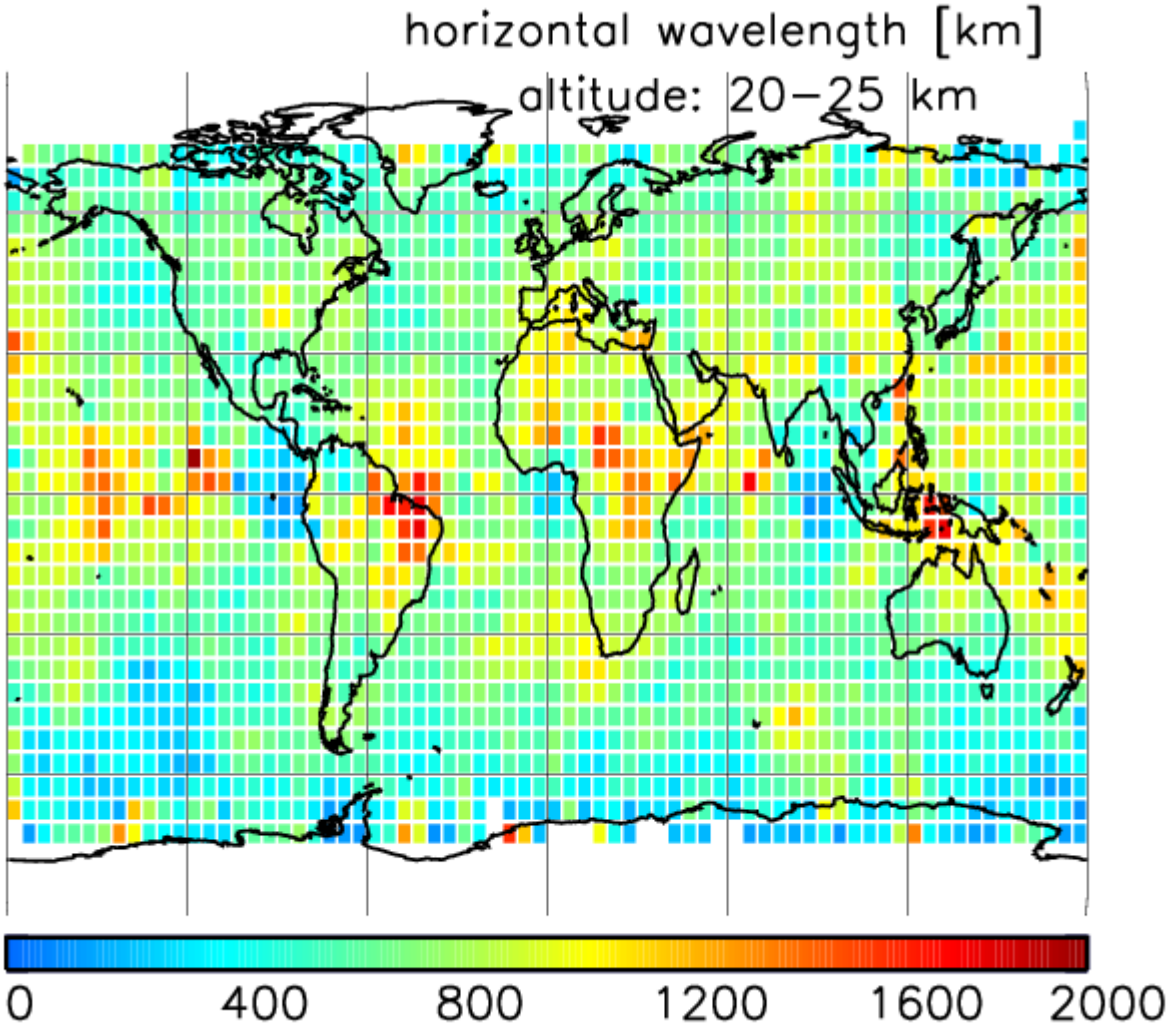
TRIADS



The different arrows represent the horizontal wavelength derived using all three measurements with different reference points within the calculation

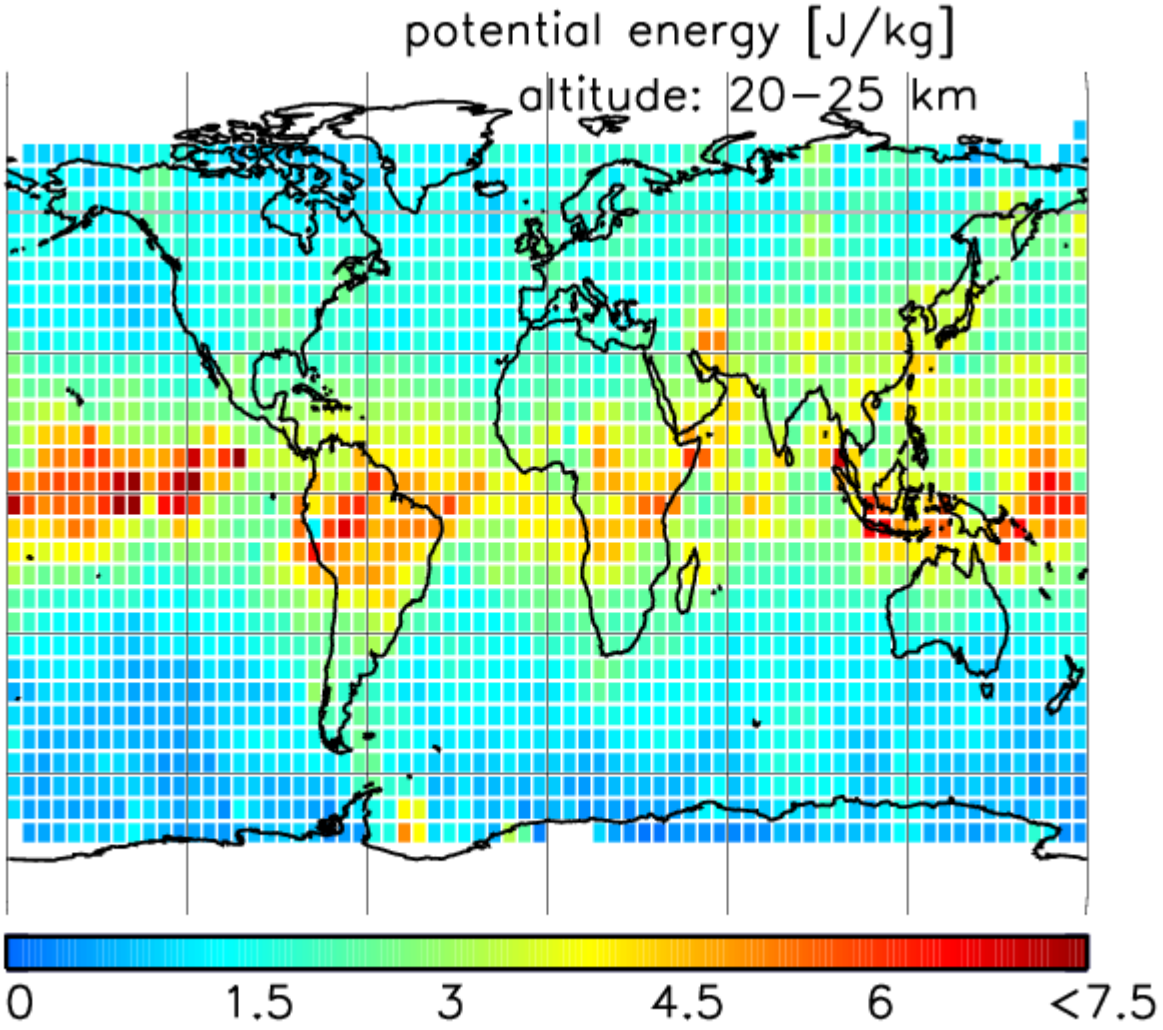
$$\Delta\phi_{ij} = k(x_i - x_j) + l(y_i - y_j)$$

HORIZONTAL WAVELENGTH



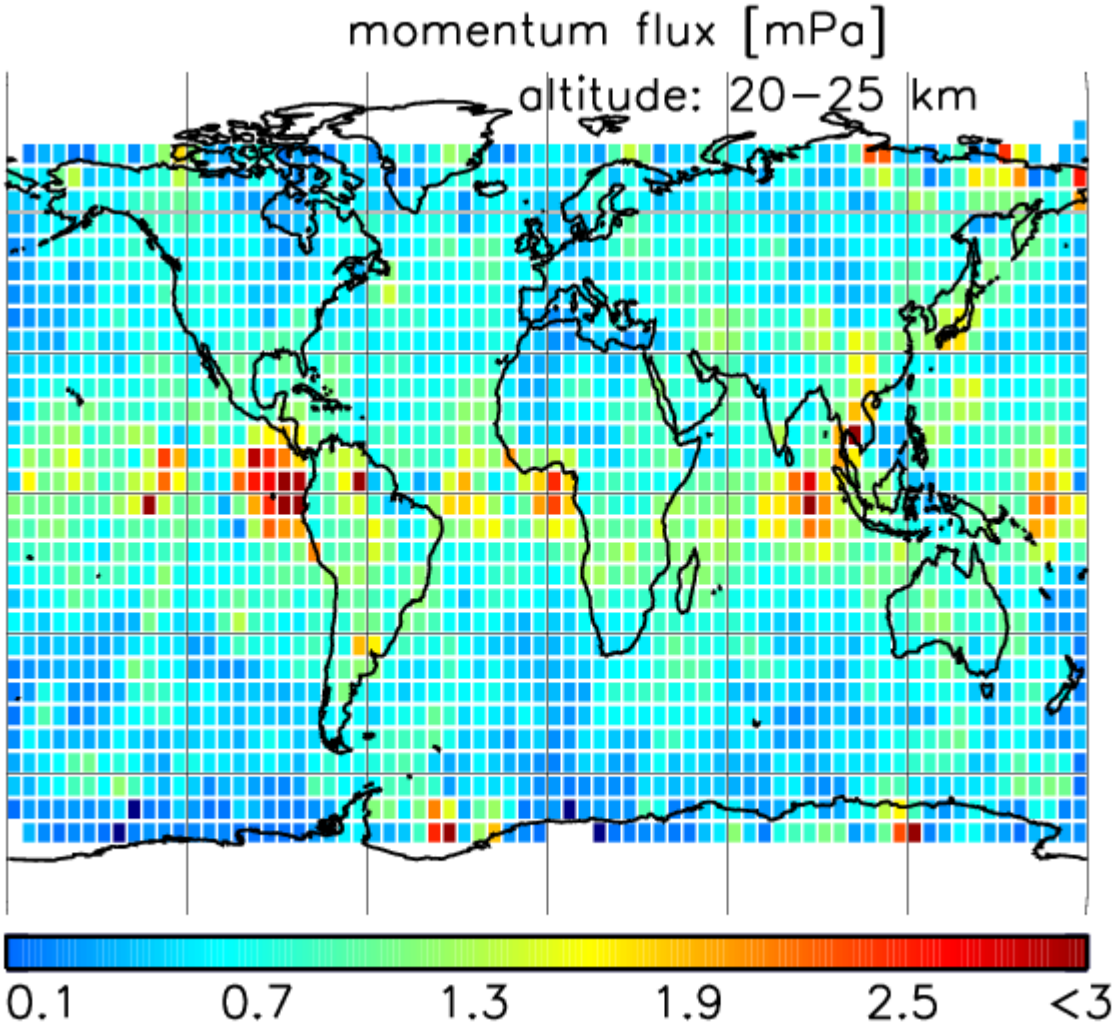
Dec., Jan., Feb. 2006/2007

POTENTIAL ENERGY



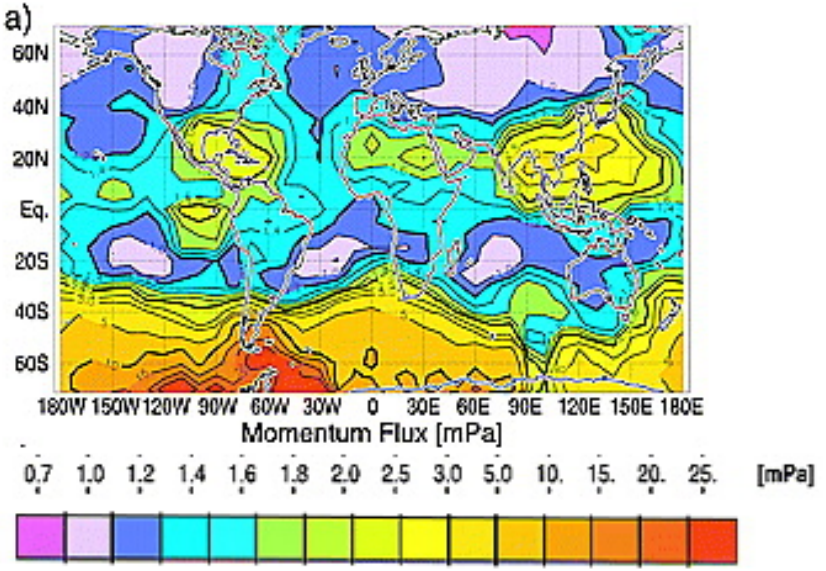
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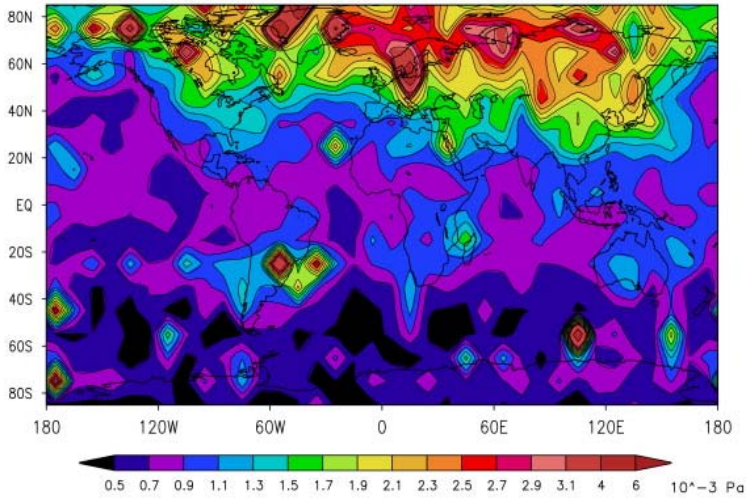
MOMENTUM FLUX

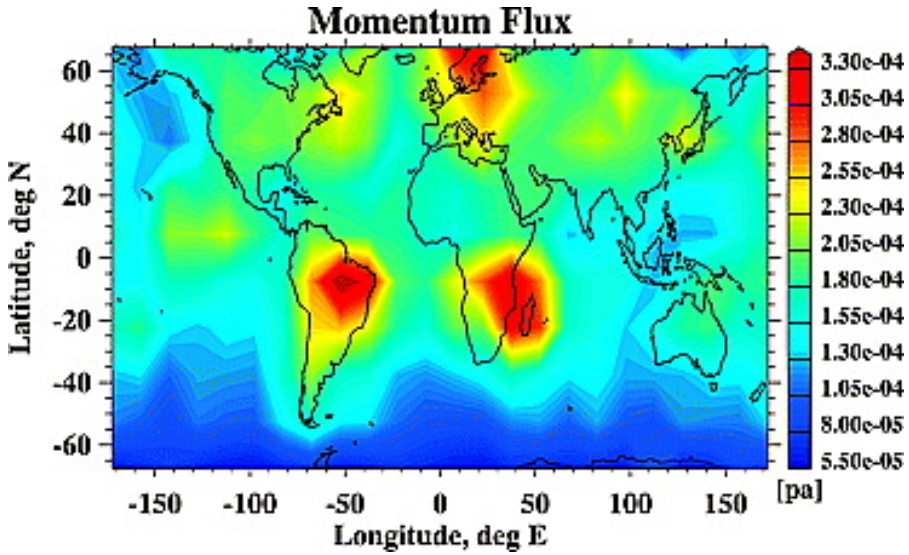


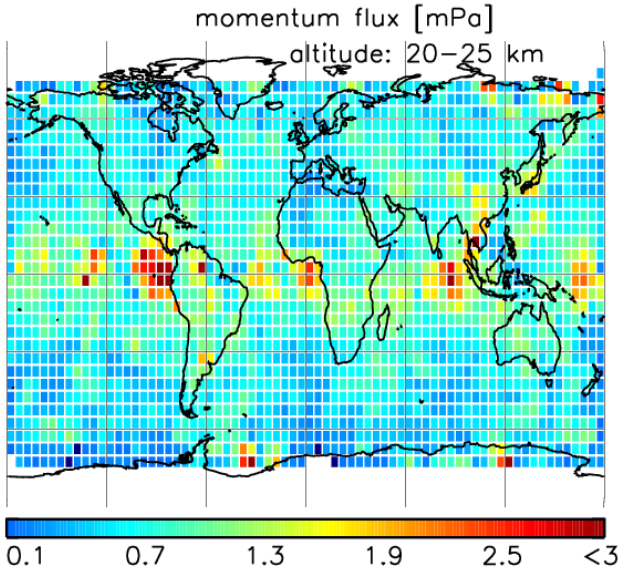
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MOMENTUM FLUX










thanks for your attention